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HIGH-ENERGY PHYSICS

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By decision taken during the ninth session of the United Nations Organization, an International Conference on the Use of Atomic Energy for Peaceful Purposes will open in Geneva on August 8. Representatives from many countries will participate in the discussions. The following article summarizes recent achievements in the physics of the atomic nucleus.

Since the day we learned that the first industrial electric power station based on atomic energy had started operating in the USSR, there have taken place many achievements in this rapidly developing field of new techniques.

The assistance promised by the Soviet Union to the states struggling for peace and democracy then assumed concrete form.

These advances are not the only contribution to the scientific development of peace-loving countries.

Soviet scientific magazines are publishing more and more reports on the work of scientists, thus laying the foundation for further progress in the techniques of nuclear transformation and contributing to a free exchange of research experience. At the recent session of the Academy of Sciences of the USSR, many of these reports were brought together. It is well known that the physics of today becomes the engineering practice of tomorrow. All the recent achievements using nuclear energy have originated in scientific investigations carried out during the last few years in the research institutes of many lands.

New investigations enable us to penetrate into the secrets of matter, thus paving the way for future achievements about which we can only guess at the present time. The forces, which have already become the property of mankind, are so immense as to threaten our existence. However, we have great faith in human intelligence and we firmly believe that human reason will prevent the use of these forces for mutual extermination. Therefore, we do not fear the publication of new findings in science. Science is an inexhaustible fount from which mankind will never cease to draw new knowledge about nature and in particular about the mysterious world enclosed within the nuclei of atoms.

Extensive publication of this new knowledge is an important element in the struggle to turn atomic energy to peaceful uses, a struggle invariably initiated by our country.

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1. Nuclear Forces

Clarification of the nature of nuclear forces, i.e. the forces holding together neutrons and protons (the particles forming the atomic nuclei), is one of the central problems of modern nuclear physics. We intend to continue examining the new particles of matter, which are called "elementary", until we succeed in finding out their real nature.

Physical research in this field was considered by many as something analogous to the "pole of inaccessibility". Nevertheless, even the most conservative "hunters for particles" are fundamentally dreamers. We may even regard their choice of a profession as an outgrowth of their romantic nature. These searchers explore Elysian Fields where every new step is pregnant with the unexpected, and new discoveries are abundant and usually concurrent with the application of powerful technical means to the developing exploration of the unknown. These investigations have become enveloped in a sort of magic shroud, probably due to the difficulty in finding normal interpretations for such research. The results of these investigations reveal so many real wonders, that cannot be fitted into the framework of conventional concepts formed at school, that they seem occasionally frightening. However, perhaps I will succeed in convincing my readers that the mastery of the new physics is not unattainable, although it requires, of course, a certain concentration of mind, even for the most superficial survey of its achievements.... But are these achievements necessary? We have already succeeded in developing means for obtaining atomic energy for peaceful purposes with the help of the processes of nuclear fission or uranium produced from the depths of the Earth. The necessary conditions for this to take place are found in special atomic reactors.

It has been estimated that if the annual production of uranium were raised to 50 thousand tons, the consumption of energy throughout the entire world could be doubled immediately. This is not utopian; the above figure corresponds to the world production of tungsten. Moreover, uranium is contained in the earth's crust in a quantity considerably exceeding that of the deposits of tungsten.

If to this we could add 100 or 150 thousand tons of thorium, from which nuclear fuel for atomic reactors could also be manufactured (and the earth's crust contains approximately three times as much thorium as uranium), then the average annual production of energy per inhabitant of the world could be brought up to approximately 200 thousand kilowatt-hours. This means that each family would have at its disposal an electric station having 50 kilowatts capacity.

Reactions occurring between atomic nuclei are not complicated. They are described in detail in a number of popular and readily available publications.

It is not surprising therefore, that some inexperienced individuals might doubt whether it is worth while to go ahead, whether it is not better to stop and develop this rich vein. Are further theoretical investigations on nuclear forces really necessary? At a press conference for representatives of the Soviet as well as the foreign press, Professor Bruno Pontecorvo

offered to explain his work in the field of high-energy physics. The correspondent of the Associated Press declined this interesting offer, visibly annoyed, and declared that he would hardly be able to understand such explanations. Our readers, however, are more eager for knowledge and more patient. Therefore, we shall try to discuss here, in brief, prospective achievements in field of nuclear physics.

First of all we wish to point out that gunpowder was also invented before scientists could explain the chemical forces acting to bind atoms into a molecule. The use of a number of other chemical transformations, for example, those occurring during the smelting of metals from ores, also arose from experience in relatively ancient times. However, everyone knows that the modern, infinitely varied, technical applications of chemistry could be introduced only after the light of knowledge was shed upon the structure of atoms and molecules and upon their ability to enter into combinations.

Nuclear physics is now at the following stage: the practical application of nuclear theory has been already achieved, although a true theory on nuclear forces has not been developed as yet.

What do the scientists know, and what do they wish to learn, about nuclear forces?

The problem as to what these forces are, arose immediately after the internal structure of atomic nuclei was discovered. To what can these forces be compared? Can they be compared with gravitational forces, which make objects thrown upwards fall towards the earth, which cause sand in agitated water to settle, and make possible the separation of cream from milk? No, the very close-knit structure of an atomic nucleus cannot be based upon forces analogous to gravity. Perhaps nuclear forces are akin to electrical forces? No, this is completely absurd. We must remember that nuclear forces operate not only with electrically charged particles, i.e. protons, but also with neutral particles, which are called neutrons. Electrical forces do not affect the latter at all.

Nuclear forces are, in their very essence, something entirely different. Electrical forces, i.e. forces of electrical attraction, and gravitational forces act over relatively great distances, and diminish gradually. Nuclear forces are known to be of a "short range" nature, i.e. their effect is felt only across very short distances, and beyond these regions they become negligible. However, in order to be able to study the interaction between particles at short distances, the particles must have a very high energy. The higher the energy of the particles, the smaller is the distance at which their interaction can be felt.

When we are compelled to work "against nuclear forces", as the physicists say, i.e. to separate the nuclear particles bound together by these forces, it becomes apparent that these forces are immense.

11. Nuclear "Glue"

We wish to cite the following comparison: the particles bound to each other in the atomic nucleus act as if fastened to each other by means of invisible and surprisingly strong rivets.

This comparison fully agrees with the concept of nuclear forces as expressed in 1935 by the Japanese physicist Yukawa. He assumed that heavy elementary particles, i.e. neutrons and protons, interact with each other exchanging some lighter particles, which act as the aforementioned "rivets" binding the interacting particles.

Yukawa's theory was never fully developed, but all the same it suggested in most general terms the existence as well as the mass of the "rivets" holding together the atomic nucleus, the mass being intermediate between that of the neutron and the proton. These hypothetical particles were called mesons ("mezos" in Greek i.e. intermediate, medium).

Even a very brief description of subsequent developments will enable us to see their dramatic nature.

A certain period of time elapsed and mesons were found. They were revealed in cosmic rays, the mysterious, continuous radiation directed towards the earth from the depths of the universe. This radiation produces great disturbances in the atmosphere. Cosmic rays destroy atomic nuclei encountered in their path. They sometimes cause heavy particles which have been transformed under their effect to shed fire-works of cosmic "showers" around them.

In 1937 K. Anderson and S. Needermeier reported that by means of the "fog chamber" (the name occasionally used for the Wilson cloud chamber, which reveals the trajectory of invisible particles) they had found charged particles in cosmic radiation. The mass of these particles was approximately 200 times that of the electron. Physicists had expected this result and greeted it with enthusiasm. Mesons had been found! The forecasts had been correct. However, the enthusiasm was followed by disappointment.

These were not the same mesons forecast in the estimations of Yukawa. These were lazy and inert mesons that interacted weakly with neutrons and protons. The physicists had expected other mesons to be discovered. One can well understand the excitement which was aroused by the announcement of the Soviet scientists A.I. Alikhanov and A.I. Alikhanyan that for the first time other "true" mesons had been found.

In 1947 the British physicist S. Powell confirmed through irrefutable experiments, the presence of charged particles in cosmic rays with a mass approximately 300 times that of the electron. These mesons (called pi-mesons to distinguish them from the other mesons) behaved in exact conformity with theoretical predictions. These mesons also interacted with neutrons and protons as expected.

The only difficulty was that in order to detect and register them, a truly great advance in experimental technique was needed; those momentary flashing creations of cosmic rays, of insignificant longevity, are extremely difficult to register. Still, they had to be thoroughly studied in the interest of nuclear physics, since they were considered the key to the fundamental mysteries of the atomic nucleus.

A new epoch opened in this field when the semi-fantastic and semi-legendary mesons, which had been so widely discussed, and whose existence had been questioned, were artificially obtained in the laboratory. The forces of cosmic power, developed in physical instruments, provided the required energy.

The circumstances under which this occurred deserve particular attention.

III. Nuclear Artillery

As already mentioned earlier, nuclear forces are immense. They exceed the forces acting between atoms in chemical compounds by hundreds and thousands of times, and are thousands and tens of thousands of times greater than the forces effective between the atomic nuclei and their surrounding layers of electrons. It is natural, therefore, that for interaction with the nucleus where these forces apply, we need particles whose energy is of the same order as the nuclear forces.

Let us decide first of all on the units in which we shall measure the energy of such charges. For this purpose we must refer to the universal unit used by the physicists for measuring the energy emitted or absorbed during the processes occurring with single atoms or nuclei. This unit is the electron volt. It is easy to guess from the name that this unit expresses the quantity of energy acquired by an electron in an electric field that has a voltage of one volt.

The energy produced by an atom of hydrogen in the process of combining with oxygen, i.e. during normal combustion, can also be expressed in electron volts. This energy is the energy of chemical combination and is 4.2 electron volts.

For comparison, let us note that the energy produced by the combination of protons and neutrons in a nucleus constitutes 7 to 8 million electron volts. An energy of hundreds of millions of electron volts, however, must be applied to separate a "meson rivet" from an elementary particle.

The attack on the atomic nucleus started with the use of natural "charges", i.e. nuclear particles transformed by the decomposing nuclei of naturally radioactive elements. Remarkable achievements, such as the first artificial nuclear transformations realized by Rutherford, production of artificial radioactive elements by Pierre and Irene Joliot-Curie, and the discovery of the neutron which is connected with the names of Chadwick and the same Curie family, have been achieved through these modest means.

However, the natural sources of particle projectiles are negligible. Selection of bombing particles is limited. In the meantime, however, the new science, which even the conservative Rutherford named with delight the "new alchemy", required the study of a wide range of nuclear reaction under the action of various particles and great energies. Special methods for attacking the atomic nucleus had to be developed and since no real task imposed by the development of science remains unsolved, nuclear "artillery" was created. This new, special nuclear "artillery" was designed to give the atomic projectiles a great acceleration to provide a considerably more concentrated fire, and to shoot a large number of projectiles of diverse kinds.

Initially the nuclear particles, to which we wished to impart a great speed in order to overcome the so-called "armour belt" of electrical repulsion protecting every attacked nucleus, were, as expressed by a Soviet physicist, placed on an "electric cliff". The "cliff" was represented by a high voltage electrical field. The particles were "precipitated" or "thrown down" from this "electric cliff" and, before reaching the "target", ran along a rectilinear course at a speed which increased as the height of the cliff increased, i.e. as a greater voltage was applied to the accelerating tubes. In these tubes the particles acquired a velocity exceeding the speed of a missile shot from a long range gun by hundreds of thousands of times, but even this proved insufficient. The projectiles necessary to overcome the "armour belt" of repulsion must be a great deal more potent in a number of cases.

At the very beginning of the development of nuclear physics, there arose the problem of whether the particles could be best accelerated in one step or in several. However, experiments on this simple idea with the help of accelerators constructed in the form of vacuum tubes stretched out in a line could lead to no decisive conclusion. To provide the accelerated particles with sufficient energy, linear accelerators of a considerable length were needed. It is sufficient to mention that in one of the modern machines the accelerated protons ran along a course 210 thousand km. long.

We may thus see why direct action accelerators could not be used for this purpose.

The solution of the problem which thus arose has been found: the particles had to be accelerated along a spiral path. Then, while completing a very long run, the particles would not move beyond the limits of a relatively small area.

In order to explain the structural principle of this instrument, the example of a sling is often used. By rotating a stone attached to a rope, we can throw the stone considerably farther than when doing so by the same hand along a straight line. However, this example merely provides a remote notion of the principle of the construction which was suggested by physicists, and it does not show its special characteristic. This special characteristic lies in the fact that the accelerated particles gain speed at each successive revolution, and only after they reach a very great speed, are they released in the

direction of the nuclear "target". In the book "New Forces" by Ralph Lapp, we find the following purely American method of description of the principle of action of the cyclotron (which is the name of this new accelerating device). He compares the cyclotron with a merry-go-round, in which every passenger receives \$100 every time he passes the cashier and thus rapidly becomes a millionaire. The idea of cyclotrons was suggested to its author, the American physicist Lawrence, not by the stock market, however, but by the new electron technique.

Particle projectiles, which are to be accelerated in a cyclotron, are inserted into the field of a powerful magnet, which causes them to move in a spiral. Having completed the run around half the circumference inside one of the dees, they enter the electrical field between the dees. The field, at this moment, is acting in the same direction in which the particles are proceeding and thus speeds them up. After this acceleration the particles continue the circular flight; however, this time around a circumference of increased radius since their speed has increased. Then, crossing once more the space between the dees, they are once more accelerated by the electric field and thus complete a full revolution. They continue to fly around this developing spiral tens and hundreds of times. At each successive revolution they are affected by a relatively small accelerating field. However, in the final analysis, the energy increases very considerably.

Encouraged by these early achievements, the scientists tried to force the cyclotron to provide the accelerated particles with more and more energy, but they encountered an obstacle which seemed insurmountable.

Nothing was changed in experimental conditions. The electrical field fluctuated in time with the revolutions of the particles, accelerating their flight. However, at a certain moment the speed of the particles ceased to increase. The particles were delayed, no longer arriving between the dees at the required moment, i.e. at the moment when the electric field would accelerate them. Thus the synchronized operation of the cyclotron became disturbed.

IV. A Hot Body is Heavier than a Cold Body

The explanation of this phenomenon (which had been discovered at a considerably earlier date than the invention of cyclotrons) may seem improbable at first sight. It appears that at increasing acceleration during circular flights, the mass of the particle changes, i.e. the particle becomes heavier. It seems as if kinetic energy accumulated in the process of acceleration overburdened the particle. You may ask - is this a semi-poetic image? Surprisingly, an increase in the energy of a particle is actually accompanied by an increase in its mass.

We must first of all dispose of any doubts as to whether the important law of the conservation of mass, which must be effective always and everywhere, is hereby violated. We know very well that mass cannot disappear under any circumstances, nor can it be produced from nothing.

Science affirms the same with regard to energy. However, for a long time science silently assumed that the two great laws of nature, i.e. the law of conservation of mass and the law of conservation and transformation of energy, were unrelated. In reality, however, one is the logical result of the other. In accordance with the law of interdependence between mass and energy, discovered by the German genius Albert Einstein in 1905, each change in the energy of a body is accompanied by a corresponding change in its mass.

The processes occurring in the cyclotron are no miracle. The phenomenon observed, i.e. the increase in mass of a particle with the increase in its energy, is completely explained by the theory of relativity formulated by Einstein.

The following example is often quoted, when discussing the theory of relativity: suppose we heat a body weighing one kg. up to 200°C and leave another body weighing one kg. at room temperature; then the hot body will be heavier than the cold body by one billionth of a gram. Of course, a balance sufficiently precise to weigh 1 kg. with an accuracy of one billionth of a gram does not exist. However, if such a balance did exist, it would show the above difference. How does this happen? Molecules of a hot body move at a greater speed than those of a cold body and the reserve of energy is actually an excess of kinetic energy of a number of separate molecules. Having a great reserve of thermal energy, the hot body also has great mass. However, since the speed of motion of particles in a heated body is considerably lower than the speed of particles flying in a cyclotron, they are not "overloaded" with kinetic energy to the same extent. Hence the difference in mass formed at the expense of kinetic energy is insignificantly small and is never detected in practice.

If we had sufficiently delicate instruments, we would be able to prove that a wound-up clock is heavier than the unwound clock. The energy increase of the intramolecular field of cohesion in a tense spring results in the increase of its mass.

A charged electrical condenser is heavier than the uncharged condenser: the energy of the electrical field corresponds to the increase in mass. This phenomenon remains unnoticed. The densities of the molecular field and of the field of a condenser are insignificantly small in comparison with the density of a nuclear field. Under normal circumstances bodies in motion, whose mass also increased in proportion to the increase of kinetic energy, do not move at speeds of tens and hundreds of kilometers per second, as is the case with particles in accelerators. However in nuclear transformation processes associated with the use of accelerators, these extraordinary phenomena become very marked. We may even affirm that physicists are quite used to them. They are now part of routine scientific and technical calculations. By considering this phenomenon, the Soviet physicist, V.I. Veksler, succeeded in laying the scientific foundation for the construction of accelerators of a fundamentally new type. As soon as this principle became known, it was successfully applied.

V. New Bombarding Machines

First of all, the difficulties arising from the effect of the increase in the mass of particles with the increase in speed arose during attempts to produce a beam of electrons at high energies. Electrons are the lightest particles and as soon as the energy reaches the order of tens of thousands of electron volts, the need for correcting for the increase in mass of the electrons becomes marked. Therefore, for the acceleration of electrons it was necessary to construct special accelerators, which were named betatrons (the term "betatron" originated from the name of the electron beam ejected by nuclei of certain radioactive substances, i.e. beta rays). However, the beta rays obtained with the help of betatrons exceeded by a hundred times in both energy and intensity the rays produced during natural radioactive decomposition. The operating principle of the betatron is very similar to that of the alternating current transformer. Every schoolchild knows that if the secondary coil has more turns than the primary coil, the transformer increased the voltage of the current. Imagine now that instead of the secondary coil the instrument is provided with a hollow ring-shaped tube, in which free electrons rotate. The number of revolutions of the electrons in this tube is analogous to the number of turns in the secondary coil. If we force the electrons to rotate in this tube many times, they will gradually accumulate great energy at the expense of the electromagnetic induction. Thus, if the cyclotron is called a "resonance accelerator", because the accelerating electric field changes therein with the rotation of the particles, then the betatron is an induction accelerator. Its main principle consists in securing the stability of the electron in its circular orbit and forcing it to rotate along this orbit many times. Physicists have shown that under proper conditions this is entirely feasible.

The year 1944 was marked by a great advance in the acceleration technique. A Soviet journal on physics published two small articles by V.I. Veksler, the Soviet scientist, which explained the new principles of the acceleration of particles. Through a simple and clever method he combined the properties of the cyclotron and betatron, thus making it possible to extend considerably the limits of acceleration. All new accelerators are now built according to this principle, one which enable us to impart to particles an energy previously encountered only in cosmic rays. The same ideas were developed by the American physicist, MacMillan.

What is the basic principle of Veksler's idea, which proved to be so successful?

He showed that stable orbits of particles are possible also in the cyclotron. Indeed, suppose the mass of a particle has increased. The period of its rotation has become so great that the electric field of the cyclotron no longer accelerates the particle, but decelerates it. But in the process of deceleration of its motion, the mass of the particle decreases anew and consequently, the period of its rotation also diminishes, as a result of which the particle will again be in a condition where the electrical field of the

cyclotron accelerates it; as a result of this acceleration the mass and the period of its rotation will increase and the particle will be once more in a condition of deceleration, and so on. In the final outcome there occurs no further acceleration in a normal cyclotron and the particle will rotate around a definite orbit. But if we gradually intensify the magnetic field or slowly decrease the frequency at which the electrical voltage accelerating the particle changes (and this constitutes the main principle of the brilliant idea of V.I. Veksler), then the particle rotating around a stable orbit will increase its energy.

All of the powerful modern accelerators of nuclear particles are built on this principle, which is explained here in very general terms.

There also exist accelerators in which the magnetic field is increased simultaneously with the acceleration of the motion of particles. These are the so-called synchrotrons, which are used to accelerate electrons.

In other accelerators the period of fluctuation of the alternating electrical current is increased simultaneously with the acceleration of the motion of particles. These are the so-called synchrotrons, which are used to accelerate electrons.

~~In other accelerators the period of fluctuation of the alternating electrical current is increased in proportion to the increase in the mass of the particle.~~ Therefore, in spite of the increased time of its revolution, the particle does not fall out of resonance, but continues to be accelerated by the electrical field. These phasotrons or, as they are occasionally called, synchrocyclotrons, are used to accelerate "heavy" particles, i.e. deuterons and alpha particles.

Lastly, the third invention has combined both operations. These are the so-called synchrophasotrons. Artificial cosmic rays, i.e. protons carrying an energy of several billion electron volts, are produced in synchrophasotrons.

Our country has not only developed the principle of these new, so-called relativistic accelerators (this term is used to characterize phenomena and instruments based on the theory of relativity), but has also constructed huge synchrotron and phasotron accelerators. Thus, for example, the largest phasotron in the world operates in the Institute of Nuclear Problems of the Academy of Sciences of the USSR. It produces protons with an energy of 680 million electron volts.

Energies with which explorers of the atomic nucleus operated two and three decades ago were only ten times greater than the energies obtained in the eighteenth century. Electrical machines, which were used as parlour toys, produced tens of thousands of volts. This value was not surpassed for two centuries. Therefore, the achievements accomplished in the course of the last twenty years are astonishing indeed.

As we have already seen, construction of these instruments, which also confirmed very exactly the theory of relativity, has met the most urgent requirements of modern physics. One important field in this branch of physics, which has been extensively developed only due to the evolution of powerful new experimental techniques, is the study of the so-called elementary processes. Under this heading are grouped, for example, the process of formation of mesons during the collision of neutrons and protons or under the effect of photons (gamma-rays of high energy), and phenomena of scattering of particles, where the forces acting between these particles operate. Work by Soviet scientists that has recently appeared in print, as the result of several years' research, is devoted to these urgent problems.

M.G. Meshcheryakov, corresponding member of the Academy of Sciences of the USSR, and Prof. S.Ya. Nikitin, with their assistants, studied in the Institute of Nuclear Problems the scattering of protons by protons. This work requires the most modern experimental techniques. It is closely connected with the use of all sorts of modern electronic equipment. Most refined methods of registration of particles with precisions up to one millionth of a second must be used. Moreover, these experiments are impossible without modern counters of nuclear particles, such as for example, certain crystals, in which the passage of charged nuclear particles produces a flare of cold luminescence, registered by means of special photoelectric multipliers.

The luminescent chamber constructed by E.K. Zavoysky, corresponding member of the Academy of Sciences of the USSR, is a remarkable achievement. The ordinary scintillation recorder registers only the bare fact of the passage of particles, whereas here, with the help of electron-optic transformers, the path along which the particles proceed in the luminescent substance is also recorded. This camera has aroused the interest of physicists in all countries.

These investigations are supplemented by the study of scattering the neutrons by protons. By comparing the two we are able to draw a number of final deductions on the nature of elementary nuclear particles. Investigations on the scattering of neutrons by protons are, however, fraught with more serious difficulties, since the neutrons carry no electric charge, and methods of their registration are much less effective than the methods of registration of protons. Nevertheless, these experiments were also successfully carried out in the Institute of Nuclear Problems under the supervision of Prof. V.P. Dzhelepov. In his report on these works delivered before the session of the Academy of Sciences of the USSR, M.G. Meshcheryakov emphasized the valuable contribution to the research in question by the theoretical physicists I.Ya. Pomeranchuk and A.Ya. Smorodinsky.

We have already mentioned that during the scattering of particles the forces in effect between these particles are displayed in the purest form. Scattering in the field of high energies makes it possible to "feel" these forces at distances too small for experiments with low energies. It is no wonder that physicists so far have been compelled to approximate by assuming that these forces are constant

up to a certain distance. This distance is called the radius of action of nuclear forces.

When two billiard balls collide and rebound, i.e. "scatter", each of them may be deflected at any angle with equal probability. In the case of the particles of atomic physics, however, the probability of deflection of particles at different angles during scattering depends essentially on the nature of the forces acting between them. Therefore, researchers are primarily concerned with the study of the so-called angular distribution of scattering. In nuclear physics these probabilities are usually characterized by cross-sections. This situation is not unusual; as a matter of fact, in artillery the probability of striking this or that target depends on the respective areas of the targets in which the chosen trajectories end. The experimentally determined magnitude of the cross-section of the elementary particles which are scattered at high energies allows one to conclude that the effective dimensions of these particles are smaller than previously assumed. It is now believed that elementary particles, i.e. protons and neutrons, are composed of small "grains" or "nuclei" (the protons and neutrons proper), which are surrounded by a cloud of pi-mesons. One cannot help thinking in this connection of the striking statement made by Lenein: "An electron is as inexhaustible as an atom".

On studying the dependence between the cross-section and energy of the scattered particles, the researchers arrived at the conclusion that possibly there exists a definite "excited" state of protons. The theory describing this phenomenon has been developed by Academician I.Ye. Tamm, a Soviet scientist.

A series of reports by the Institute of Nuclear Problems of the Academy of Sciences of the USSR has been devoted to the study of the formation and properties of pi-mesons. These promising reports were produced by M.G. Meshcheryakov and Prof. M.S. Kozodaev. In their experiments they investigated charged pi-mesons, as well as neutral pi-mesons. These promising reports were produced by M.G. Meshcheryakov and Prof. M.S. Kozodaev. In their experiments they investigated charged pi-mesons, as well as neutral pi-mesons (the latter exist as well as the former).

The reaction between two protons, in the course of which heavy hydrogen (deuterium) and a positively charged pi-meson are formed, is of special interest among the nuclear reactions connected with investigations on charged pi-mesons. This reaction, as well as its converse, where the deuterium and a positively charged pi-meson interact producing two protons, can also be experimentally investigated. This is a most interesting example of equilibrium in nuclear reactions.

A new citizen of the Soviet Union, the progressive Italian scientist Bruno Pontecorvo, who is now working in our country, has carried out a fine piece of work in the field of high energy nuclear physics. He successfully investigated the scattering of charged mesons by deuterons and protons in those high energy regions which up to that time had been little studied.

Investigations on the interaction of neutrons and protons with complex nuclei are also of great interest, since such interactions show the manner in which particles composing the nuclei are arranged therein. Until recently nuclear reactions at high energies were investigated only by cosmic rays, with the help of Wilson's chamber and thick-layer photographic films, i.e. the method proposed for the first time by the Soviet scientists L.B. Mysovsky and A.P. Zhdanov.

With the help of these methods, results of such reactions were observed in the form of peculiar "stars", composed of many streaks formed by charged particles being simultaneously emitted from the point of collision. But only the charged products of such reactions were capable of being observed. The successful new nuclear "artillery" makes it possible to study such reactions under laboratory conditions as well. One may mention the recently published work by Prof. V.I. Goldansky and his assistants who studied the division of heavy nuclei by neutrons of high energy. By means of neutrons with an energy of about 400 million electron volts they investigated the division of not only uranium and thorium nuclei, but also considerably lighter nuclei: bismuth, gold, tungsten and others. It appeared that the division of nuclei at this energy reveals an interesting and peculiar property: before the division a great number of neutrons, occasionally more than ten, are liberated from the nucleus.

This peculiar division has been investigated using photographic emulsions by Prof. N.A. Perfilov, a Leningrad physicist; radio-chemically it has been investigated by Prof. B.V. Kurchatov in cooperation with his and Academician A.P. Vinogradov's assistants.

Investigations carried out by many diverse methods made it possible to determine the fundamental differences in the nature of the division of heavy and light nuclei caused by high-energy particles.

But how can one explain the simultaneous discharge from the nucleus of such a great quantity of secondary particles? We cannot, of course, discuss this problem thoroughly in this article. This division can be explained only through analogy. Just as particles of water escape from a heated tea kettle, so we may think of a nucleus into which a high-energy particle has penetrated as boiling and evaporating the neutrons contained therein.

We must not think, of course, that this division can produce a chain reaction. Nuclei of comparatively small mass (such as bismuth, tungsten, and gold) divided only under the effect of very fast particles which can be obtained only by means of artificial acceleration requiring the consumption of quantities of energy. For this reason, the neutrons ejected before division are unable to induce a chain reaction. Nevertheless, this phenomenon is certainly of great interest from the theoretical point of view, being a phenomenon characteristic of reactions at high energies.

A series of interesting experiments devoted to the interaction of gamma rays having an energy of up to

350 million electron volts with nuclei and elementary particles, were carried out on the synchrotron of the Lebedev Physical Institute of the Academy of Sciences of the USSR under the supervision of V.I. Veksler, the inventor of the principle on which accelerators of the new type are built, and a corresponding member of the Academy of Sciences of the USSR, together with Prof. P.A. Cherenkov, the noted Soviet physicist.

The outcome of this research was reported at the conference on cosmic rays, which took place during the winter of 1954. We also wish to mention the research conducted on the formation of neutral and negative pi-mesons by the hydrogen isotope, deuterium, as well as investigations on the interaction of gamma rays and copper and nickel nuclei, which provided information forming the basis of a new concept in the structure of atomic nuclei, i.e. the development of the nuclear shell model.

These and many other experiments of Soviet researchers show that our country occupies one of the leading places in the field of high-energy physics.

Recently there was held an All-Union Conference on quantum electrodynamics and the theory of elementary particles with special emphasis on mesons. Foreign as well as Soviet scientists took part in this conference where new theoretical papers by Soviet scientists were widely discussed and highly approved. They were also widely discussed at the session of the Academy of Sciences of the USSR on the peaceful uses of atomic energy.

We think it appropriate to refer once more to the history of the discovery of mesons. This history has not been completed as yet and the undiscovered areas are pregnant with promises of new discoveries. When "creating" new particles by super-powerful accelerators, the researchers discover one meson after another. They are now considerably more numerous than needed, or, more accurately, than the existing theory can explain.

This is the most exciting and troublesome period in the history of this science. The river is still covered with ice but spring waters beneath it are restless. A little while yet and the icy armour of obsolete theory will crack and a flood of new ideas will carry away the old ice floes.

This was the case with chemistry, when the researchers were compelled to face manifestations of differences in the properties of molecules of a uniform chemical composition, which were difficult to explain from the viewpoint of the old theories. The genius of Butlerov developed a new theory which embraced all these extraordinary facts.

The same occurred in physics, when the necessity of explaining the mysterious facts of natural radioactivity led to the formation of modern concepts on the structure of the atom, this complex structure with a nucleus surrounded by clouds of electrons.

The physics of the atomic nucleus is now at a similar stage of development, unstable and rich in achievements, and we all know that it signifies the beginning of a new upward flight (or "breakthrough").